1941

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BULLETIN OF THE UNIVERSITY OF NEBRASKA STATE MUSEUM

C. BERTRAND SCHULTZ, DIRECTOR

VOLUME 2 LINCOLN, NEBRASKA, DECEMBER 1941 NUMBER 8

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THE pipy concretions of the Arikaree (lower Miocene) of Nebraska and adjacent states were first described by Nelson Horatio Darton (1899, p. 743) as "characteristic layers of hard, fine-grained, dark-gray concretions, often consisting of aggregations of long, irregular, cylindrical masses" (see Figures 30, 32, 34, and 35). The individual pipes vary in diameter from a few inches to several feet, and in length from a few inches to a hundred yards or more. Tests demonstrate that pipy concretions are composed of sand cemented by calcium carbonate. When dipped in acid the cement is dissolved and the concretion is reduced to incoherent fine sand. No explanations for the origin of pipy concretions have been made but it seems rather generally agreed by field observers that they were formed by "underground water."

Darton (1899, p. 743) noted that pipy concretions had regular directional trends which were "east-northeast and west-northwest with surprising regularity." Later he (1903b, p. 2; 1903c, p. 2) mentioned also that the trend of the longer axes of the pipes is east-northeast and west-southwest in the Camp Clark and Scotts Bluff, Nebraska, quadrangle areas. J. B. Hatcher (1902, p. 116) also observed that the pipes in the Arikaree sandstones along Pine Ridge in Sioux County, Nebraska, had a general northwesterly and southeasterly trend. The present writer (1938, p. 443) has also called attention to the fact that "the concretions are somewhat systematically directed," but no one has given reasons for this apparent regularity.

During the field season of 1933, while exploring for vertebrate fossils in the Arikaree deposits of western Nebraska, the writer examined pipy concretions in many localities in Nebraska and decided to attempt to determine accurately their directional trends with the aid of a compass. This project was carried out in order to learn whether there was any orderly arrangement of the pipes which might be of regional extent. In the summers of 1934, 1935, and 1936, during the course of paleontological explorations, a series of compass readings was taken by the writer and his assistant, Gordon Graham, and the results were later checked with the aid of a Brunton compass. Each reading was obtained by orienting the compass on a concretion and observing the direction of its longitudinal axis. In order to obtain sufficient accuracy, readings were taken for a number of pipes at each station and an

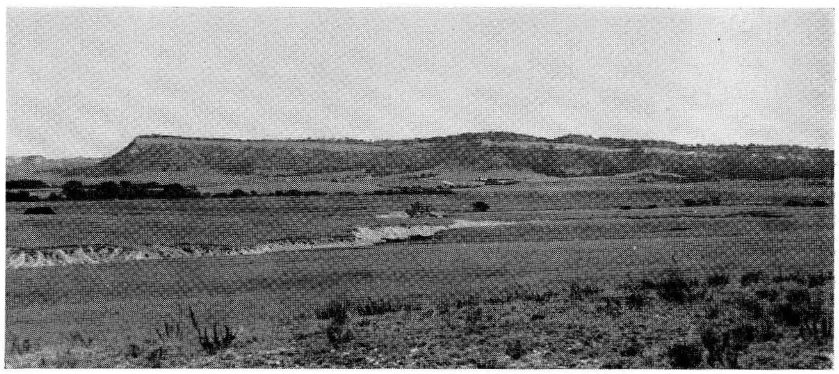


Fig. 28.—Pine Ridge east of Five Points, Sioux County, Nebraska. Gering and lower Monroe Creek largely talus covered; upper Monroe Creek = bare, perpendicular exposures; Harrison = pine-covered top of ridge.

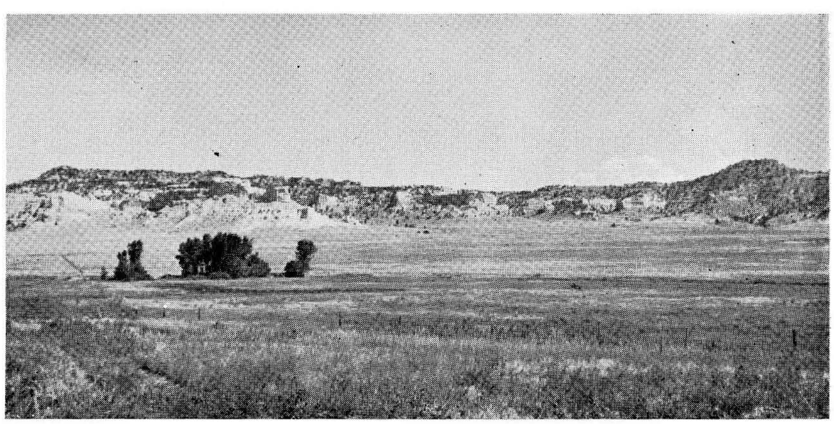
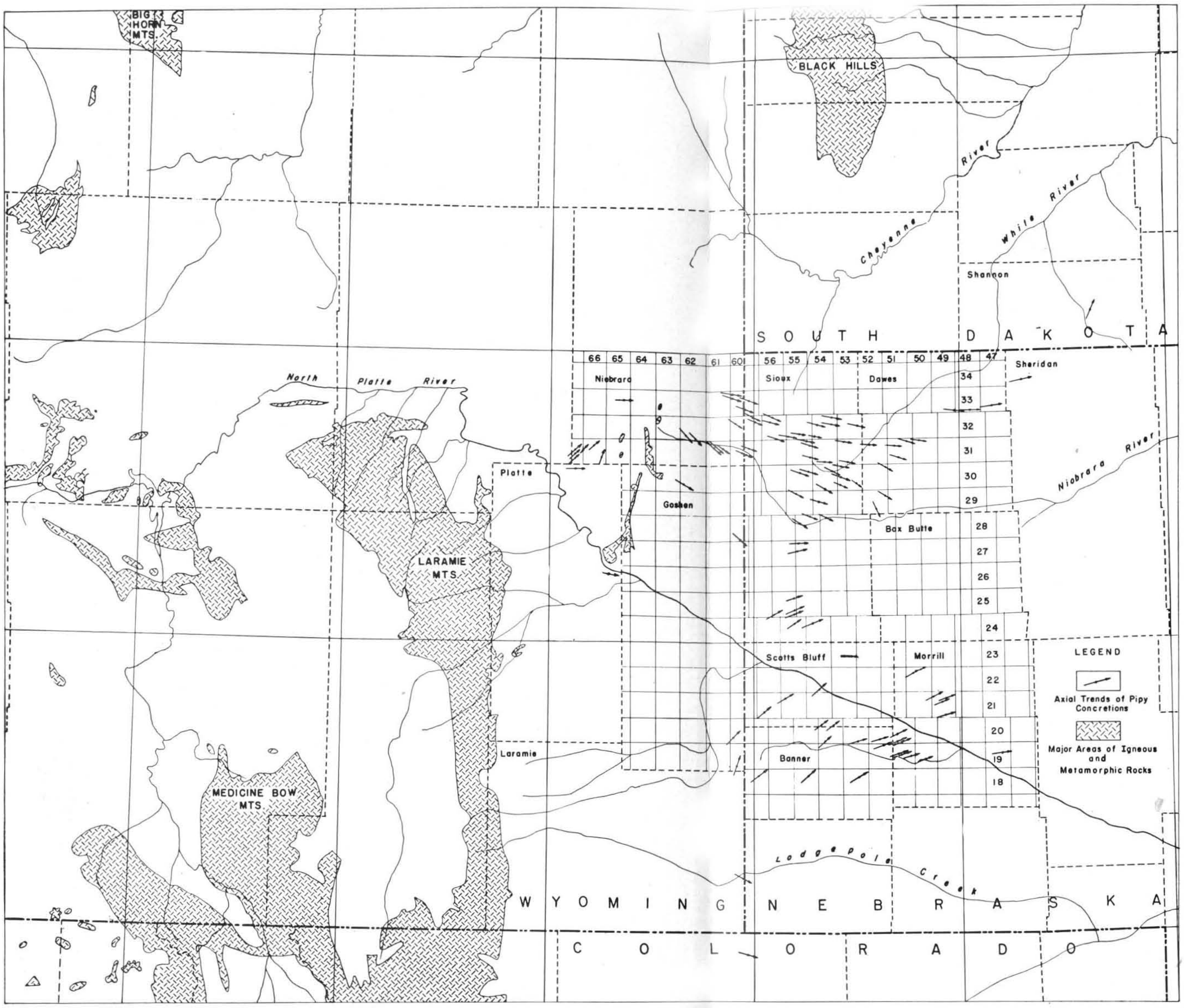


Fig. 29.—Hogback and Wildcat mountains, Banner County, Nebraska. Exposures of Arikaree (Gering, Monroe Creek, and Harrison), with Brule (Whitney member) at base and Ogallala at top.



THE AXIAL TRENDS OF PIPY CONCRETIONS IN THE LOWER MIOCENE DEPOSITS (ARIKAREE GROUP) OF WESTERN NEBRASKA AND ADJACENT STATES

SCALE
10 0 10 20 Miles

By C. Bertrand Schultz

Base Outline after United States Geological Survey Map average was recorded. Rarely did the readings vary more than a few degrees in any one locality. The declinations of 14° and 15° were used according to the locality as figured from an Isogonic Chart of the United States Coast and Geodetic Survey for 1930. Exact locations of stations down to the quarter section were recorded whenever possible.

Plate I shows the results of plotting all stations on a map of western Nebraska and adjacent areas, with arrows indicating the

Fig. 30.—Typical pipy concretions in Arikaree deposits, Wildcat Ridge, Scotts Bluff County, Nebraska.

directions followed by the pipes. The major areas of igneous and metamorphic rocks were plotted in order to determine if possible whether these regions of uplift in any way influenced the axial trends of the pipy concretions.

Underground water apparently did play a very important part in the formation of the concretions, for carbonate of lime is the principal cementing agent in the Arikaree concretions, and was undoubtedly collected, transported, and deposited by ground waters. Waters flowing eastward from the regions of uplift in the west probably dissolved out soluble calcium carbonate from the Paleozoic limestones which were exposed in the higher areas. These solutions may have become further concentrated by the leaching out of soluble silica in the volcanic ash disseminated through Miocene sands.

The porosity and permeability of the Arikaree sands probably had much to do with the distribution of the concretions. A perme-

Fig. 31.—Pseudo-pipes in Arikaree deposits north of Bridgeport, Morrill County, Nebraska.

able rock, with respect to subsurface water, is one having a texture which permits water to move into or through it without impairing its structure or displacing its parts. Porosity refers to the amount of spaces or interstices contained within a rock. The following statement was made by H. J. Fraser (1935, p. 912), who is an outstanding authority on porosity and permeability:

> Many geological processes are greatly influenced by the porosity and permeability of the rocks involved. This is particularly true in the case of sediments . . . . Porosity and permeability vitally influence the compaction and consolidation of sediments . . . .

Fraser (1935, pp. 990, 1008–9) also reported that both porosity and permeability are not uniform throughout a deposit and in that connection continued as follows:

> The effect of more permeable lenses in an otherwise homogeneous sedimentary bed is as follows: The solution will advance equally along a front at right angles to the plane of the bed until it comes in contact with the first (porous) lens. Through this it will advance much more rapidly. When the end of this lens is reached, the solution will further advance through the main bed, radiating out from the lens, not only from its end but also from its sides. Eventually connections will be made with the next lens and the foregoing process repeated. Finally, a condition of continuous flow will be established through the bed to some adequate outlet. The main volume of solution will then pass along the path of least total resistance, or maximum permeability, which will be along the lenses wherever possible. Although flow will be concentrated through the lenses, there

will also be subordinate flow throughout the surrounding portions of the main bed for a distance determined by the frictional resistance and for so long as the interstices remain open.

These processes, together with the changing of water tables, may adequately explain the formation of the concretions of the Arikaree. The pipes were formed by lime solutions flowing through areas or lenses of highest porosity and depositing calcium carbonate there. The general form of the concretions may have been determined by the original deposition of more and less permeable sediments. In areas where most of the sands were equally porous the flowing water spread wide and resulted in the formation of large sheets of concretions rather than pipe-like forms. Examination of many of the more massive layers of concretions shows that there are in reality many individual pipes arranged parallel to each other with numerous connections between them. This would suggest that a condition of nearly continuous flow existed when the concretions were formed. Occasionally narrow perpendicular "tubes" are found extending through pipy concretions. Such tubes are probably solution cavities, although there has been little speculation concerning their cause.

Many of the pipy concretions might be thought of as "horizontal stalactites." The growth of a pipe was accomplished in much the same way as that of a stalactite except, in the case of the pipy concretions, the solution of lime flowed horizontally through porous sediments instead of dripping from the ceiling of a cavity, and the concretion, instead of being made up entirely of the cementing material, incorporated the surrounding matrix into itself. Hence the upper or large end of a "pipe" is always to the west, the direction from which ground-water solutions were flowing during the lower Miocene times. The lime-charged water slowly moved through the sediments to the east by gravity and capillarity. Some of the lime was deposited in the porous areas around sand grains or other nuclei and many repetitions of this process caused the formation of long, slender, icicle-shaped incrustations of calcium carbonate. The size of the concretion depended upon two things, the porosity of the sediments and the length of time that the process continued. The stability of the water table undoubtedly controlled the latter factor. If the water table continued to exist at one level for a long enough period, the concretion would grow and perhaps come into contact and fuse with others.

The vertical distances between pipy layers vary greatly in any section of the Arikaree. There may be as much as fifteen or twenty feet between layers but usually this distance is considerably less. Often several are found together in the form of a massive layer four feet or more thick. Such layers appear as large lenses and cannot be traced for great distances, hence it is almost impossible to correlate the pipy layers of two sections which may be located only a few hundred yards apart.

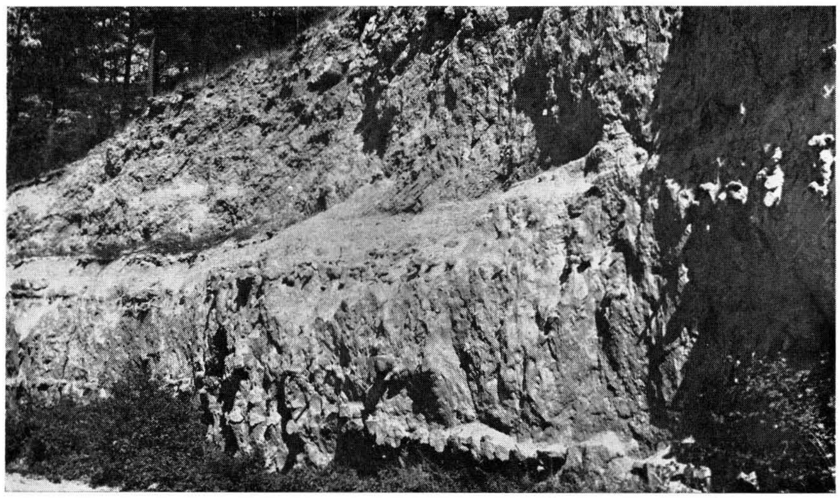


Fig. 32.—Layers of typical pipy concretions in lower Monroe Creek deposits, Monroe Creek Canyon, Sioux County, Nebraska.

That the Arikaree concretions were formed shortly after the deposition of the sediments in which they are found is demonstrated by the presence of great quantities of water-worn Gering and Monroe Creek concretions in the basal Harrison conglomerate, which is well exposed along Wildcat Ridge and north of Bridgeport. Post-Monroe Creek erosion must have uncovered quantities of lower and middle Arikaree pipes which were subsequently deposited in basal Harrison sediments. Pipes occur throughout the Arikaree, but they are best formed in lower Monroe Creek deposits along Pine Ridge (see Fig. 32) and Wildcat Ridge. A few pipes also are found in the Gering, especially in the region of the Nebraska-Wyoming line, and in the Harrison, chiefly in the basal deposits. Unusual concentrations of Harrison pipes are observed at the base of that formation in some localities, especially north of Bayard (see Fig. 34) and Bridgeport as well as along Pine Ridge. This concentration may be accounted for by the fact that these basal deposits are of coarser texture and apparently more porous than most of the Arikaree sediments.

The pipes of the Harrison are often covered with irregular sand-calcite crystals (see Fig. 35) and are somewhat more varied in

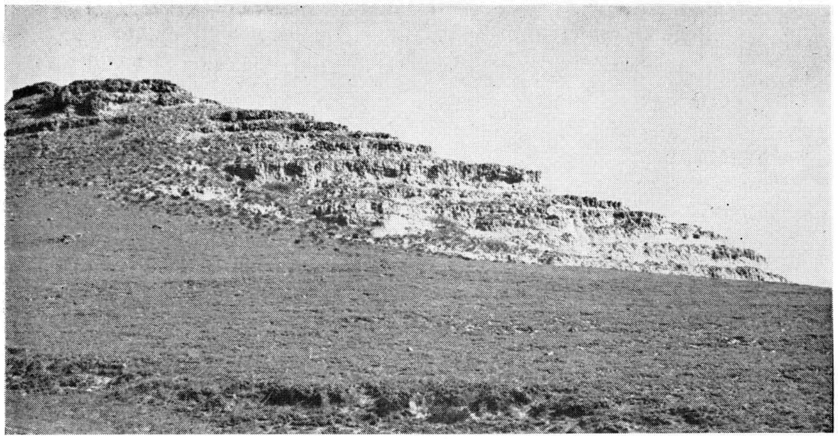


Fig. 33.—Arikaree (Gering and Monroe Creek) deposits, showing well-developed pseudo-pipy zones, 4 miles north of Bridgeport, Morrill County, Nebraska.

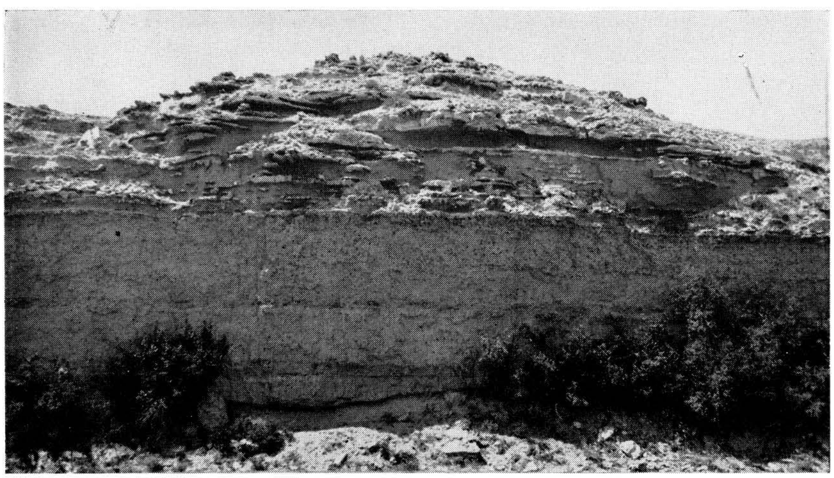


Fig. 34.—Arikaree deposits (Gering or Monroe Creek = massive perpendicular lower part of section; Harrison = pipy concretionary zone above), 8 miles northeast of Bayard, Morrill County, Nebraska.

form than the typical examples of the lower Monroe Creek. Occasionally the pipy concretions of the Harrison appear to be made up of ball-shaped concretions which may be fused together (see Fig. 35). Barbour (1901, p. 166) first called attention to this when he stated:

It is interesting to note the occurrence of every condition and every possible gradation from solitary spherical concretions to strings of partly united concretions, then to pipes, which we shall consider as made up of an infinite series of spherical concretions.

Fig. 35.—Pipy concretions covered with irregular sand-calcite crystals, in the Harrison formation, 6 miles northwest of Harrison, Sioux County, Nebraska.

This type of concretion occurs much more frequently in the Marsland. Figure 37 shows the eroded surface of a Marsland form with the typical concentric growth lines of many individual ball-like concretions which have fused together into a large massive structure. In Figure 36 the upper example illustrates a pipe-like structure made up of numerous small ball-like concretions fused together. The lower left object in the same figure demonstrates that many of the ball-like forms taper to a point on one side. The large ends of the individual concretions were to the west, the direction from which the ground-water solutions apparently were flowing during Marsland times.

The term "pseudo-pipe" was suggested to the writer (1938, p. 442) by Mr. S. R. Sweet of Bridgeport, Nebraska, in 1933, for pipe-like concretions which are irregular in shape. These are often small nodules or knob-like forms, but in places form layers or sheets of irregularly shaped concretions (see Figs. 31, 33). The sheet-like structures may be in the form of rather discontinuous, horizontal masses which have parallel furrows or ridges on their upper surfaces. Many of these concretions (Fig. 31) appear to con-

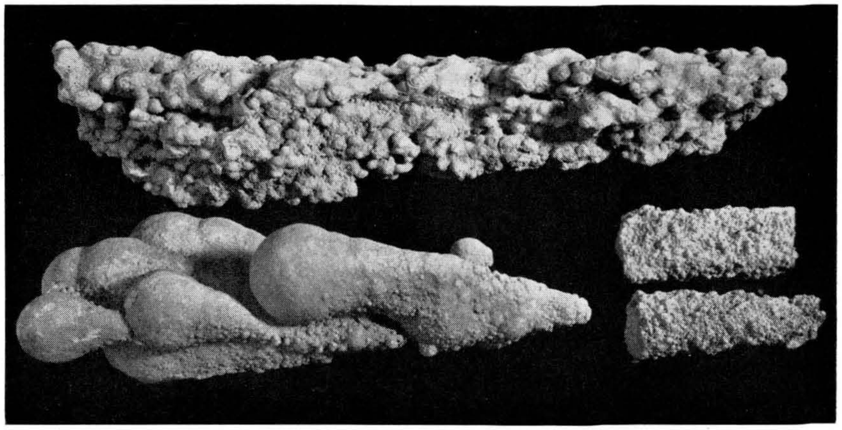


Fig. 36.—Concretions from the Marsland formation, 6 miles northeast of Agate, Sioux County, Nebraska.

sist of numerous small concretions which stand with the longer axes perpendicular instead of horizontal, suggesting that the ground water of lower Miocene times may have acted at times in both horizontal and perpendicular directions. Pseudo-pipes characterize the upper Gering and the upper Monroe Creek but are not restricted to these horizons. Most of these forms appear to have been formed in finer grained and less pervious sediments than the true pipy concretions.

Although the pipes in any one locality appear to be parallel to each other, a few exceptions have been found where the variations were as much as twenty degrees within a distance of a few hundred yards. Two localities where axial trends vary this much are near Signal Butte in Scotts Bluff County, Nebraska, and at Sixty-six Mountain on the Nebraska-Wyoming line. Such variations must be expected, especially when it is realized how much the Arikaree sediments themselves vary. Local structures and even old inherited drainage patterns may have influenced the direction of the pipes. In some localities the pipes are not horizontal but slope somewhat as if following the contour of an early Miocene valley. Present-day water tables in general follow the contours of the earth's surface, with "valleys" and "hills" corresponding to physiographic terrain. This might well account for the sloping Miocene concretions.

The axial trends of the pipy concretions shown on the map (Plate I) indicate the direction of flow of the underground waters during Arikaree time. These waters flowed in definite directions from major areas of uplift. A study of the directional readings of the pipes in the Hartville Uplift region in eastern Wyoming suggests that the solutions flowed around it. This was confirmed during 1940 when the writer observed that the pipes southwest and south of the Hartville Uplift pointed to the southeast and east respectively. Since it is evident that the pipes encircle uplift areas, it is possible that small anticlinal structures can be located by detailed mapping of the pipes in restricted areas. The map also shows the occurrence of several lower Miocene basins, including a large one in the east-central portion of the Nebraska panhandle in the vicinity of Box Butte, southeastern Dawes, northeastern Morrill, northern Garden, and southern Sheridan counties, as is indicated by the direction of the majority of the arrows. Other basins existed in northeastern Colorado and in South Dakota.

In nearly all localities in Nebraska and Wyoming where the writer took magnetic readings of the axial trends of pipe-like concretions in the Arikaree there is little or no variation in a comparatively wide vertical range, i.e., in a section several hundred

Fig. 37.—Eroded surface of concretions from the Marsland formation, same locality as Fig. 36.

feet or more thick. This would indicate that the general courses of the underground waters were fairly constant during lower Miocene times. A check of the directional trends of concretions of the Hemingford and Ogallala shows that they often differ considerably from those of the Arikaree. If the directions of these later concretions were plotted on maps, patterns of the underground water courses of those times could perhaps be observed.

It is possible that the genesis of some of the massive, sheety, concretionary layers of the Arikaree can be explained by the caliche theory. Gilbert Lueninghoener[1] (1934, p. 50–1) suggested that the hard layers of the Ogallala which contain a high percentage of calcium carbonate are of caliche origin. Deposits of this type were formed by capillary action which caused the ground water containing dissolved salts to come to the surface, especially during times of great aridity. The water evaporated, leaving the mineral salts as a crust on and near the surface of porous sediments.

Concretions arranged in parallel rows have also been found in marine deposits in several localities in the United States, but they must have had a much different origin than the pipy concretions of the Arikaree. J. E. Todd (1896, pp. 347–9) described some interesting log-like concretions from the Pierre of South Dakota and thought that they represented ripple marks of an old fossil shore. Concerning a picture of the phenomenon Todd made the following statement:

> It represents a series of these concretions extending a distance of 100 feet and lying in strict order end to end, on either side others are seen less regularly arranged with their axes approximately parallel. Closer examination revealed the fact that they are composed of fine sand cemented together with calcareous material and showing wavy laminations or ripple marks. . . . In cutbanks more or less transverse to the axes of the concretions, they were seen to project like logs from a flood deposit. . . . Nothing seemed more rational than to suppose that these systems of concretions represent ancient beaches or fossil shores. Differential sediments from wind and rain might be sufficient to determine the centers for concretionary action.

Todd noticed that the directions of the axes of the concretions could be followed for miles and often formed broad curves.

Ripple marks are also known (Hyde, 1911, pp. 257–79) from the Salem and Berea formations at the base of the Mississippian section of Ohio, and from deposits of the Richmond group of the Ordovician of Indiana, Kentucky, and Ohio.

Concretions which somewhat resemble those of the Arikaree are reported from the upper Weskan member of the Pierre shale in Wallace County, Kansas, by M. K. Elias (1931, p. 81), who suggests in the following quotation that their parallel arrangement and regular spacing may have been due to wave or current action:

[1] Professor of Geology, Midland College, Fremont, Nebraska.

In the type locality, also in some other exposures, the concretions are in the form of very long bodies arranged parallel to each other and lying along the same bedding plane. Thus they make erosional banks consisting of prominent parallel ridges spaced a few feet apart. These ridges are about one to one and one-half feet across and many times as long and are often sliced by close-set parallel cleavages perpendicular to the axes of these bodies.

Somewhat similar and equidistantly spaced, cylindrical concretions have been noticed in a few outcrops of the basal concretionary zone of the Salt Grass member described below. The regular spacing of the concretions along a bedding plane is puzzling. The concretions are elliptical in cross-section and can hardly be interpreted as secondary deposition of calcium carbonate along and beyond possible vertical joints in the shale. Their equidistant spacing might be due to wave or current action and thus they could be classified with paripples or large ripples with wave lengths measured by feet.

Current ripple marks consistent with the directions of velocities of the currents often occur in flood-plain deposits, but they are small and would hardly account for the large pipe-like concretions of the Arikaree.

Many interesting problems for future investigation have been presented in this study of the pipy concretions. A detailed lithologic and chemical analysis of the Arikaree sediments with special emphasis on the concretions would be worth while.

The writer wishes to acknowledge his appreciation to Dr. Erwin H. Barbour for his permission to carry on the work on pipy concretions in connection with regular Museum field work; to Mr. Gordon L. Graham for aid in obtaining the readings of the directions of many of the pipes; to Dr. A. L. Lugn, and Messrs. Charles H. Falkenbach, Thompson M. Stout, Gilbert Lueninghoener, and E. L. Blue for advice and assistance in the field; and to Mr. John Mercer for help in preparing the manuscript.

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